^{60}Fe project: barium fluoride detector 19 pack characterization

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^{60}Fe is seen in a variety of places on earth and in space even though it only has a half-life of 2.64 million years, quite small compared to the life span of the solar system[1-3]. ^{60}Fe must thus be produced recently in the universe. The clear electromagnetic signature associated with ^{60}Fe can be used to help model the stellar evolution of star if enough knowledge about its nucleosynthesis is learned[4]. When ^{60}Fe is initially produced by neutron capture on ^{59}Fe it is produced in an excited state; which can re-emit the neutron or deexcite via gamma ray emission. The photon strength function describes the bulk quantum mechanical component of photon emission probabilities and thus it is important in describing this reaction. For some nuclei, experiments have shown an enhancement in the photon strength function at very low energy; this feature is commonly referred to as an up-bend. This up-bend has large potential ramifications for r-process nucleosynthesis. Experiments have shown an up-bend in the ^{56}Fe and ^{57}Fe nuclei[6], so the observation of its presence in ^{60}Fe would illustrate that this feature may be more widespread. Learning how the photon strength function varies across the chart of nuclides would also aid in modeling the neutron economy of advanced reactors.

A test run was conducted on November 1st of 2019 to begin testing the equipment to be used for the ^{60}Fe photon strength function experimental set up. 7.5 MeV/u ^{57}Fe was impinged on a CD_2 target to do a ^{57}Fe(d,p)^{58}Fe reaction . The free protons produced in this reaction in the angular range of approximately 120 to 150 degrees were detected by an annular silicon detector. Gamma rays produced from excited states in ^{58}Fe were detected using a hexangular arrangement of 19 BaF_2 detectors. A parallel plate avalanche counter was also employed to measure the ^{58}Fe residue produced in the reaction and for beam tuning purposes. This report shall focus on the performance of the 19 pack of BaF_2 detectors.

Gamma rays can undergo Compton scattering or pair production, which can spread their energy out over multiple detectors, or cause some energy to go unmeasured. The energy of the of the gamma rays detected, and the gamma ray multiplicity associated with the event are important observables for extracting the photon strength function. To attempt to correct for this problem neighboring detectors that fired next to each other in the same event are added together. Code to do this was adapted from the DANCE project at Los Alamos Lab. The effect of this is shown from the comparison made in Fig. 1. The gamma ray spectrum is shown for individual BaF2 crystals' recorded energies within a 100ns of the silicon trigger (blue) with the yield normalized to one. On top of this spectrum is the gamma spectrum when these same crystals are "clustered" together (red), again normalized to one. When contiguous neighboring crystals are added together the 810 keV corresponding to the first excited state to the ground state transition in ^{58}Fe becomes more prominent. This enhancement suggests that the clustering method is successfully reconstructing gamma rays. In addition, there is a clear enhancement in the yield at higher gamma ray energy and a reduction in the relative yield of the 511 keV region as pair produced annihilation photons are added back to reconstruct their higher energy gamma ray progenitors. The low energy Comptons at around 200 keV are also reduced in intensity under the clustering method regime.

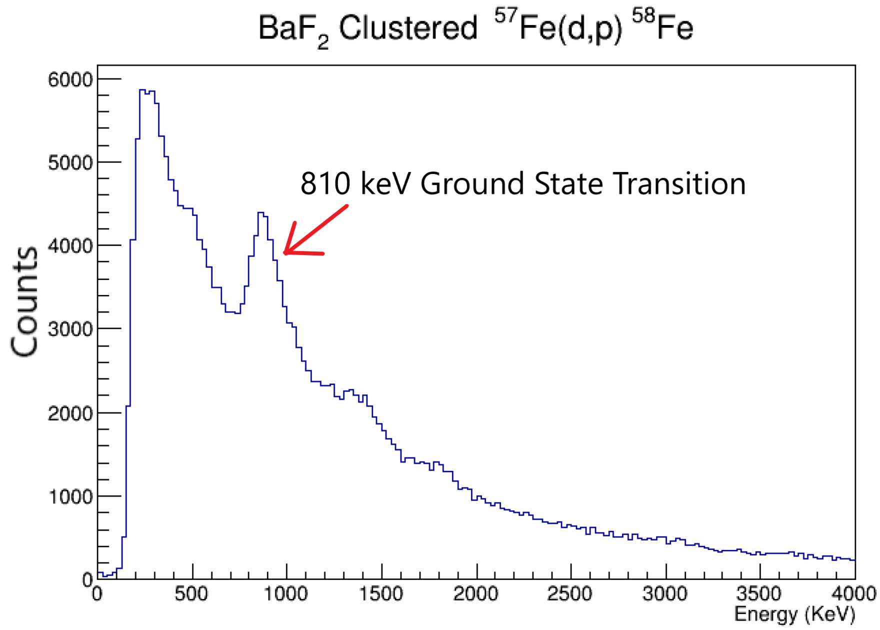

Fig. 1. In blue is the energy of any individual crystal that triggered within 100ns of the silicon detector triggering. Plotted in red is the clustered gamma spectrum, instead of taking the individual crystal energies contiguous crystals that triggered have their energies added together. Both spectra are normalized to one.

The other key observable in the experiment is the excitation energy calculated for the residue. This information is calculated from the backward silicon detector's measurement of the protons emitted in the reaction. Using the proton's energy and the know kinematics of the reaction the excitation energy is calculated [8]. For the purposes of the photon strength function analysis if the total gamma energy calculated is not sufficiently close to the excitation energy calculated the event is thrown away. The excitation energy detected in the silicon detector is plotted against the sum of the energy detected in the BaF2 detectors in Fig. 2. From this figure it is obvious that in most of the events there is incomplete collection of the gamma energy. This is unsurprising because in this test run only 19 BaF2 detectors were used, much less than the proposed 128 BaF2 detectors for the final setup. The events where there is more energy collected in the pack than excitation energy comes from cosmic contamination and the presence of carbon fusion events.

The 19-Pack performance is a good step in the direction of the final experimental setup. A clustering routine from DANCE has been successfully utilized to reconstruct gamma rays. Clearly there is still room for improvement, especially in acquiring greater solid angle coverage and to select out fusion events. In a future test run a 37 Pack of BaF2 will be used in addition to the 19 Pack to improve coverage. Further test plans involve the use of a TOF measurement of the residues to gate out the fusion contamination.

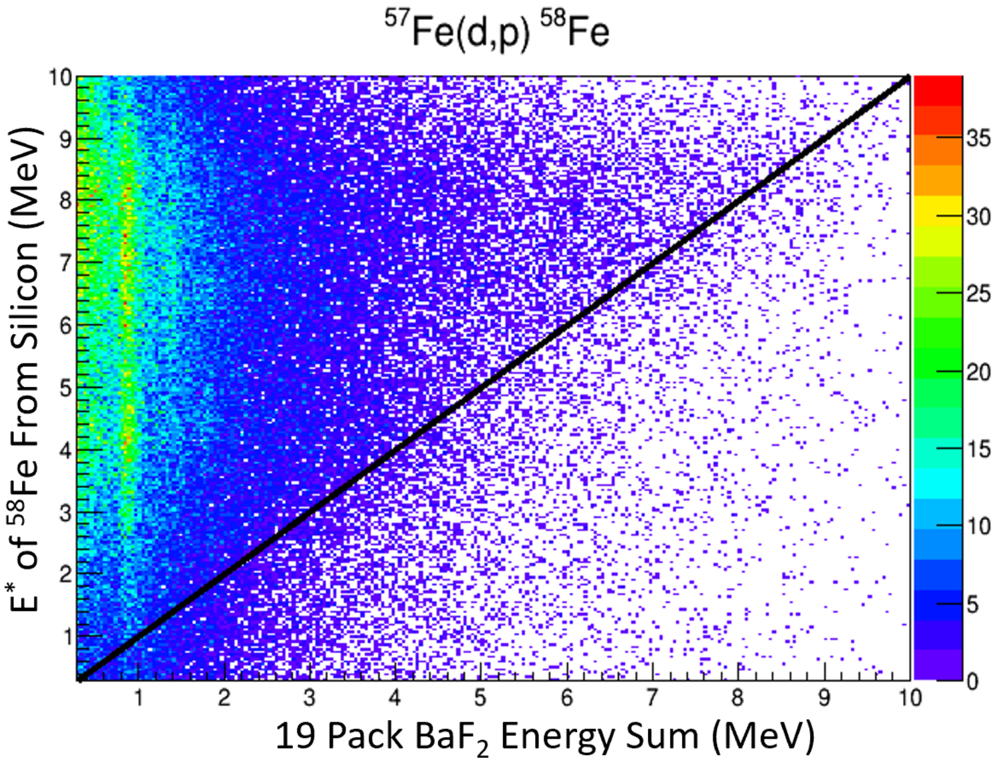

Fig. 2. The excitation energy of the ^{58}Fe residue calculated from the proton detected in the annular silicon detector is plotted against the sum of all the energies collected in the 19 Pack of BaF_2 detectors. The diagonal black line is the y=x line, which points out potentially complete events.

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